# An Alternate Shear Connector for Composite Action

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In Iowa, there are over 20,000 bridges on the secondary system. The majority of these bridges are the responsibility of the local county engineers who with limited budgets, frequently design and construct short span bridges with their own labor forces. The primary objective of the research presented in this paper is to perform laboratory testing on an alternative that counties can design and construct. This project involves testing and modifying a system of steel beams with concrete fill between them. This system has been used by several Iowa counties on low water stream crossings for more than 20 years. There is no reinforcing steel in this system or connection between the steel beams and the concrete. With the proposed modification which uses an alternate shear connector (ASC) for composite action, less materials will be required and longer spans will be possible. Key words: composite action, shear connector, shear strength, bridges, steel beams.

## INTRODUCTION

This paper will provide an overview on the use of an alternate shear connector (ASC) for obtaining composite action. The ASC was conceived as a means of using an existing bridge alternative on longer span bridges. The existing alternative is referred to as a beam-in-slab-bridge (BISB).

In Iowa, there are a significant number of BISBs on low volume roads. As shown in Figure 1, the structure uses a series of steel W sections spanning between abutments. The majority of bridges constructed to date have used W10 and W12 sections on 2 ft (0.61 m) centers. Steel straps are welded to the bottom flanges to hold the steel beams in place while the concrete is placed; there is no reinforcing in this system or physical connection between the steel beams and the concrete. Plywood, placed between adjacent beams on the top surface of the bottom flanges, is used for form work. The width of the forms is made a few inches less than the beam spacing so that the concrete is in contact with the bottom flange when placed. Thus, even after the form work deteriorates there will be adequate bearing between the steel and the concrete. These structures have been used for spans varying from 20 ft (6.10 m) to 40 ft (12.19 m) with and without guardrails.

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Upon reviewing this system, the authors determined that by making two modifications to the beam-in-slab system (adding composite action and reducing the weight of the structure), it would be possible to increase the strength of the system and use the system on longer spans. Also, if the top flanges of the beams were removed from the riding surface, the skid resistance of the bridge surface could be improved. In the BISB system, there is sufficient concrete to carry compressive forces without the contribution of the top flange of the steel beams. The two modifications investigated were: 1) developing composite action between the concrete and steel and 2) reducing the size of the concrete slab.

Leonhardt, et al. *(1)* have shown that by punching holes in the web of the steel sections, composite action between the concrete and steel can be developed. Concrete dowels are formed when concrete fills the holes. These concrete dowels resist the horizontal shear at the steel-concrete interface and prevent vertical separation of the two materials. Transverse reinforcement in some of the holes is required to confine the concrete to the steel. This type of shear connector has also been investigated by Roberts and Heywood *(2)* and is similar to Perfobond strips shown in Figure 2 that were tested by Oguejiofor and Hosain *(3)*. Concrete on the tension side of the BISB (see Figure 1) is obviously providing minimal strength contribution and thus is essentially only adding to the dead load of the system. By replacing the plywood forms with sections of arched formwork (corrugated metal pipe or plastic pipe) as shown in Figure 3, the amount of concrete on the tension side can be significantly reduced. Pipe formwork of the appropriate diameter will provide the desired slab thickness (dimension 'h' in Figure 3). Coring holes through the web of the steel beam with steel reinforcement through several of the holes (i.e. the ASC) will make it possible to obtain composite action. Incorporating these modifications to the beam-in-slab system would make it possible to use this system on significantly longer spans with reduced cost. Even with these modifications, the simplicity of the beam-in-slab system permits it to be constructed by county work forces.

## RESEARCH RESULTS

This investigation consists of several tasks to address the desired modifications: Static push-out tests for determining the strength of various types of ASC between concrete and steel; cyclic load tests of the ASCs for determining their fatigue characteristics and slip behavior; use of ASCs in composite beam tests for strength and behavior data. In the following sections, each of these tasks will be briefly described.

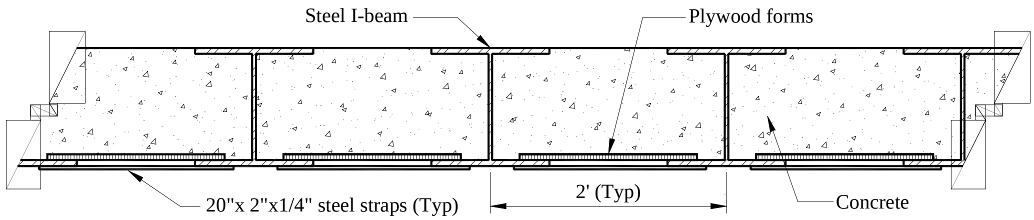



**FIGURE 1 Beam-in-slab bridge system (1 in.=25.4mm)**

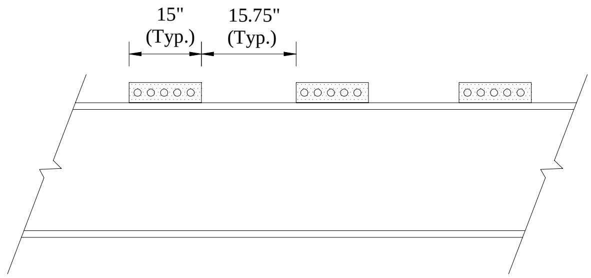



**FIGURE 2 Perfobond ribs on top flangeof steel beam (1 in.= 25.4 mm)**

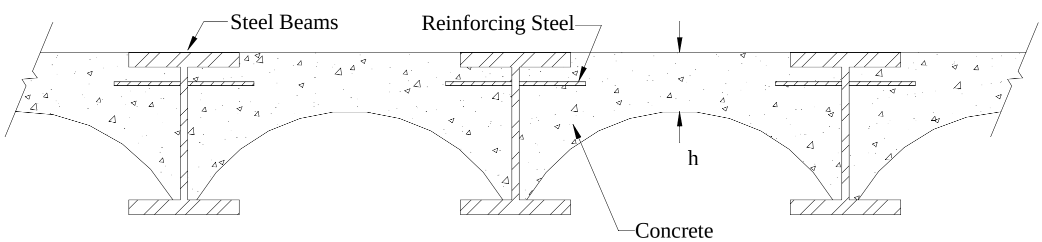



**FIGURE 3 Modified beam-in-slab system (1 in.= 25.4 mm)**

## Static Push-Out Tests

Dimensions of the push-out specimens are shown in Figure 4. As shown, each specimen consisted of a stiffened steel plate 3/8 in. (10 mm) x 20 in. (510 mm) x 15 in. (380 mm) and two concrete slabs: 8 1/4 in. (210 mm) x 21 in. (535 mm) x 20 in. (510 mm). In each specimen, the steel plate and reinforced concrete slabs were positioned so that the contact area was 17 in. (430 mm) x 2 1/2 in. (65 mm) in each slab for a total contact area of 85 $in^2$ (54,840 $mm^2$). Load was applied to the steel and transmitted into the concrete slabs through shear; voids at the bottom of the steel plates (see Figure 4) prevented transfer of force by bearing.

Eleven series of push-out tests were completed. Variables investigated include hole diameter, hole spacing, hole alignment, addition of reinforcement through a hole, reinforcement size, and cored vs. torched holes. The configuration of holes in the steel plate and presence of reinforcement, etc. in 10 of the 11 series are illustrated in Figure 5. Series 7 involved plain steel plates and thus has not been included in this figure. In reviewing Figure 5, one notes there are three series without reinforcement (Series 1, 2, and 3) and two series with torched holes (Series 8 and 9). There were 3 specimens in each series except for Series 1 in which there were 6 specimens; thus, a total of 36 push-out tests were completed.

Slip and separation between the steel plates and concrete slabs were measured on all push-out specimens. The instrumentation for all specimens consisted of seven direct current differential transformers (DCDTs). Two of the DCDTs were positioned to measure slip between the concrete slabs and steel plates, four to measure separation at two elevations along the slab, and one for detecting lateral deflection of the stiffened plate. The two slip readings obtained were averaged to produce the average slip per connector. The load per connector is one half of the total load applied to the specimen. Separation between the concrete and steel was very small and thus could be neglected. Out-of-plane movement of the stiffener plate was also determined to be very small.

Typical load-slip data for some of the series tested are presented in Figures 6 and 7. Shown in Figure 6 is the load-slip data from Series 1 and 10; both these series have 1 ¼ in. (30 mm) diameter holes on 3 in. (75 mm) centers. The only difference is Series 10 also has a #4 reinforcing bar. Comparing the two curves in this figure one notes the increase in strength resulting from the added reinforcement. The effect of torching holes vs. coring holes in the steel is illustrated in

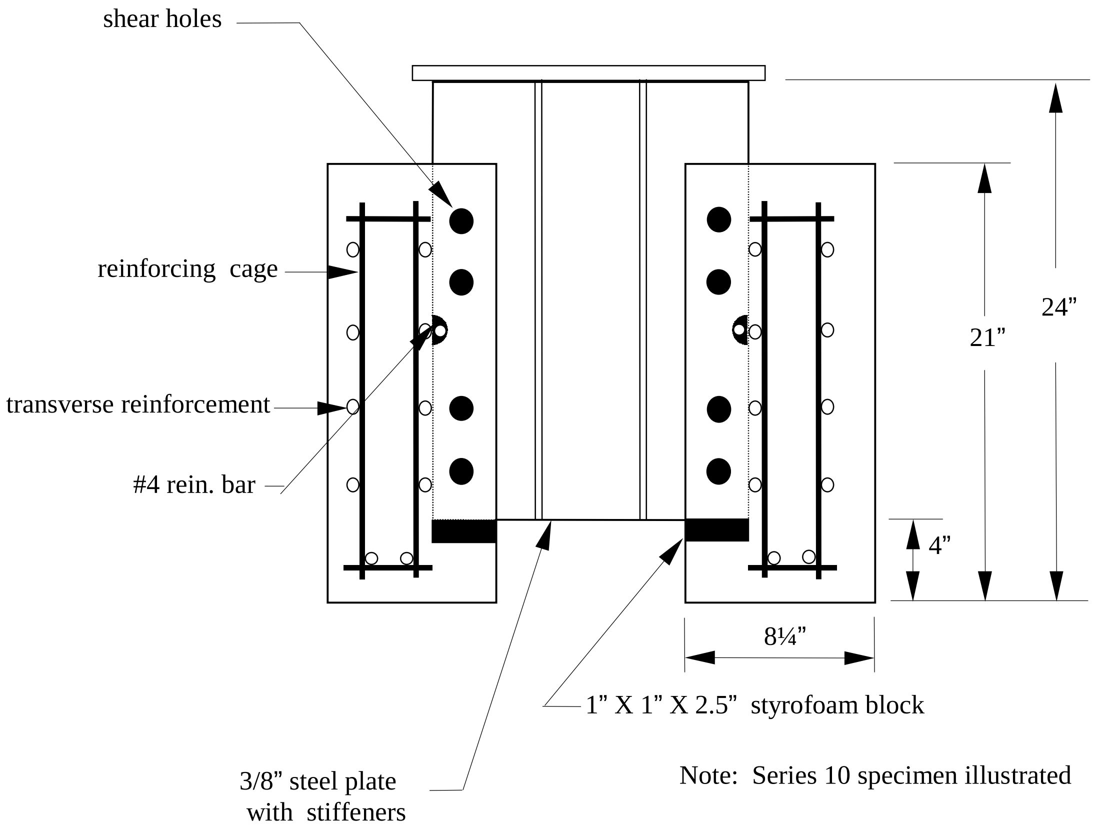



**FIGURE 4 Details of push-out specimen (1 in=25.4 mm)**

Figure 7. As indicated, poor quality torched holes have slightly less strength; however, carefully torched holes have essentially the same strength as cored holes.

From the results of the tests, it was determined that the strength of the ASC was influenced by five variables: concrete compressive strength, the friction between the steel plate and the concrete, the concrete dowel formed by concrete, the reinforcing bar placed through the shear hole, and the transverse slab reinforcing. It was also determined that hole spacing was not an important influence on the strength of the connection if the spacing was at least 1.6 times the hole diameter. Therefore, spacing of the shear holes was not included in the design equation that was developed, however, the design equation is only valid for hole spacings greater than 1.6 times the shear hole diameter.

In reviewing beam sizes that might be used for bridge stringers, it was determined that the smallest web thickness that might be encountered in the field would be approximately 3/8 in. (10 mm), which is the plate thickness used in the push-out specimens. Therefore, steel plate thickness also was not included as a variable; the expression developed will thus result in conservative strength values for web thicknesses greater than 3/8 in. (10 mm).

Using the experimental data from the various push-out tests, an equation (*4*) was developed for predicting the shear strength of the ASC. The primary factors that influence the shear strength of the ASC are the concrete compressive strength, the number and area of the shear holes, and the amount of transverse reinforcement.

### Fatigue Strength of the ASC

Push-out specimens (see Figure 4) were also used to determine the fatigue strength and slip behavior of the ASC when subjected to cyclic loading. Three series of specimens were tested: Series FS1, which is the same as Series 10 in Figure 5i; Series FS2, which is the same as Series 5 in Figure 5e except #4 reinforcing bar used instead of a #3; and Series FS3, which is the same as Series 1 in Figure 5a except #4 reinforcing bar added to center hole. A total of 21 specimens were subjected to cyclic loading. Results from these tests indicate the ASC has adequate capacity for use in typical single span bridges. There was minimal strength gained by staggering the shear hole alignment (Series FS1 vs. Series FS2). Also, the reinforcement in full diameter holes (Series FS3) is more effective than reinforcement in half-circle holes (Series FS1).

### Use of ASC in Composite Beams

To obtain additional strength and behavior information on the ASC, three full-scale composite beam specimens (two static and one fatigue) and two full-scale two-beam specimens representing potential bridge systems were constructed and tested. The ASC was used in all five specimens. As was previously noted, this portion of the investigation is still in progress, thus only information on the two beam specimens (Specimens 4 and 5) is presented in this paper. Both of these specimens were 34 ft (10.36 m) in length.

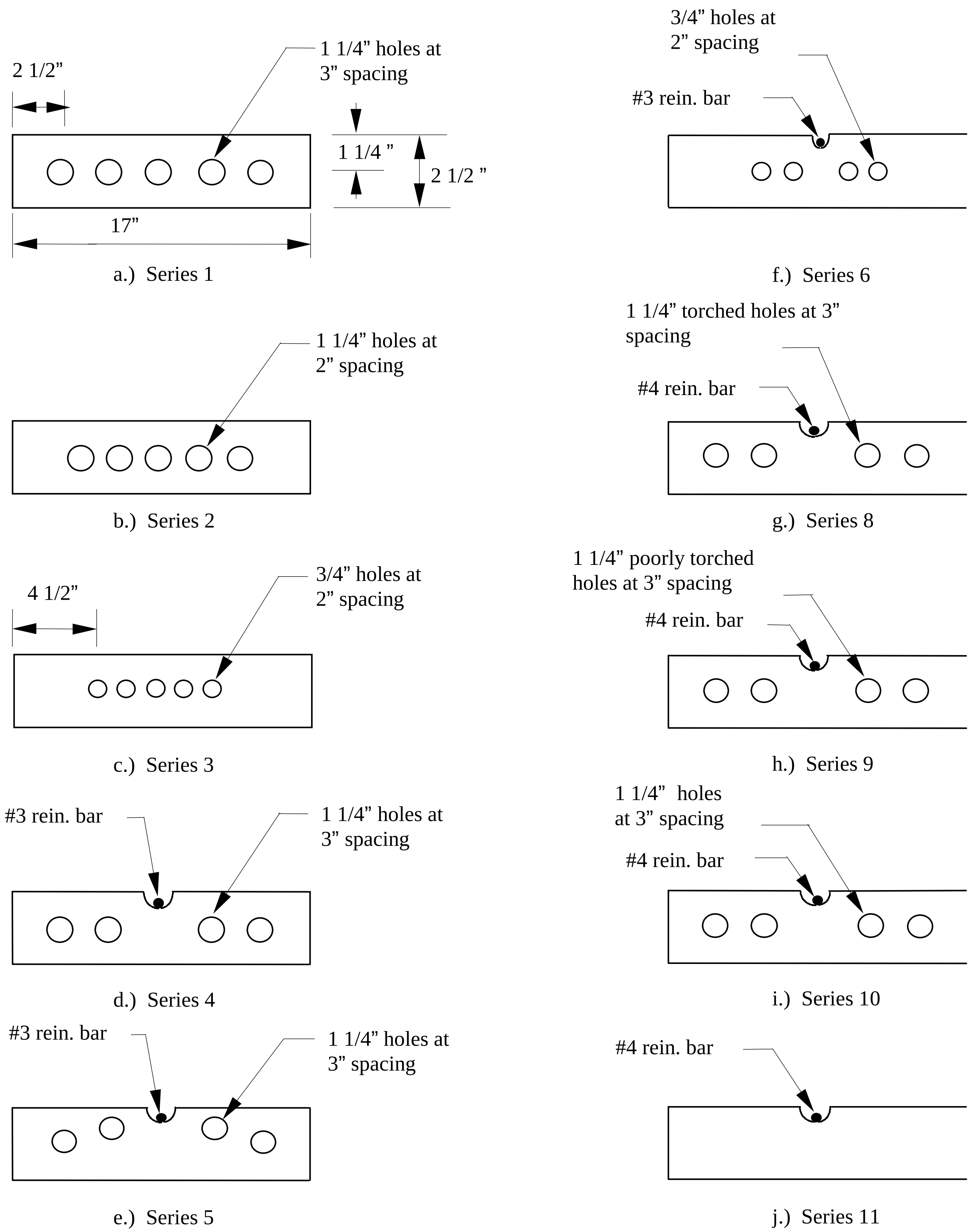



**FIGURE 5 Details of hole arrangements used in push-out tests (1 in.=25.4 mm)**

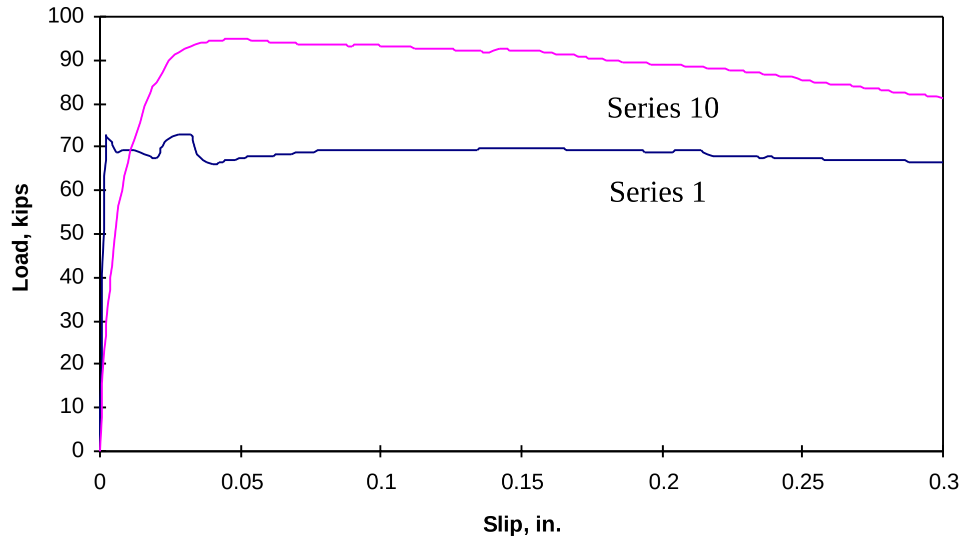



**FIGURE 6 Load-slip curves for series 1 and 10 (1 in.=25.4 mm; 1 kip=4.45 kN)**

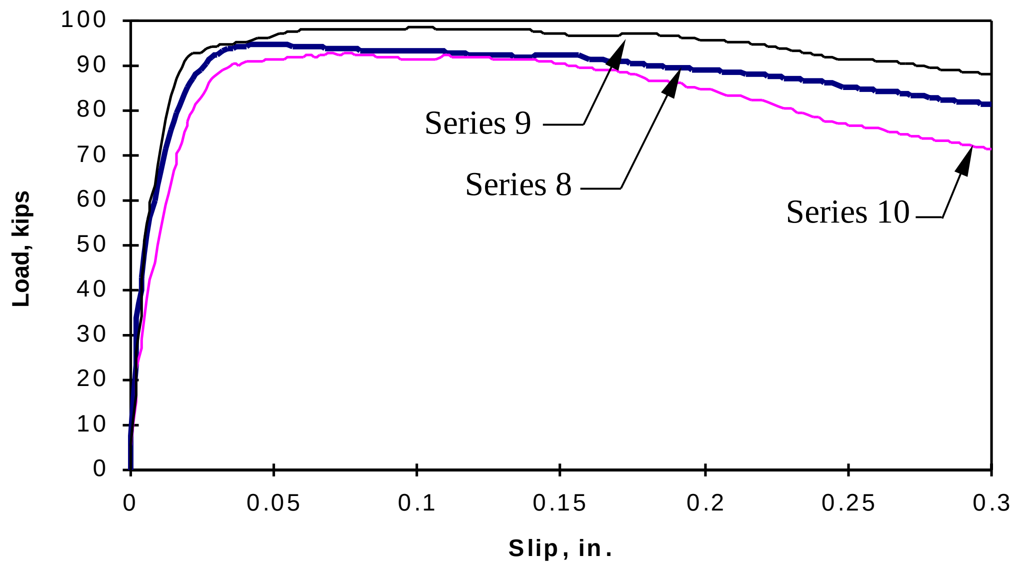



**FIGURE 7 Load-slip curves for series 8, 9, and 10 (1 in.=25.4 mm; 1 kip=4.45 kN)**

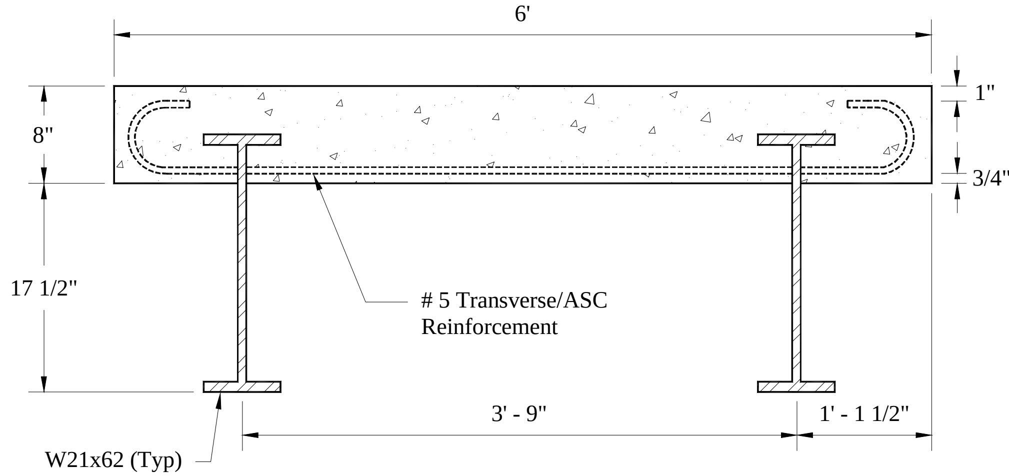
Specimen 4, as shown in Figure 8a, consisted of two W21 x 62's with their top flanges embedded in an 8 in. (205 mm) concrete slab. As may be seen in this figure, the only reinforcement in the slab was #5 bars placed every 15 in. (380 mm) through the 1 1/4 in. (30 mm) diameter holes which were torched in both beams. The reinforcing system in Specimen 4 is based on the Canadian steel-free deck research *(5)*. A steel-free deck obtains its strength through an arching type behavior of the concrete slab with the beams acting as the supports and the reinforcing steel providing the lateral restraint (tension ties). The transverse reinforcement in Specimen 4 has a dual purpose; it acts as a tension tie between the beams, and it contributes to the strength of the ASC. To obtain proper development of the transverse steel, it was necessary to provide the hooks illustrated.

Specimen 5, shown in Figure 8b, consisted of two W21 x 62's fully embedded in a concrete arch system which spans between the beams. This specimen is more directly related to the modified BISB (shown in Figure 3) in that it incorporates removing some of the concrete on the tension side of the specimen and using the ASC for composite action between the steel beams and concrete. Transverse reinforcement in this specimen is #4 bars on 15 in. (380 mm) centers.

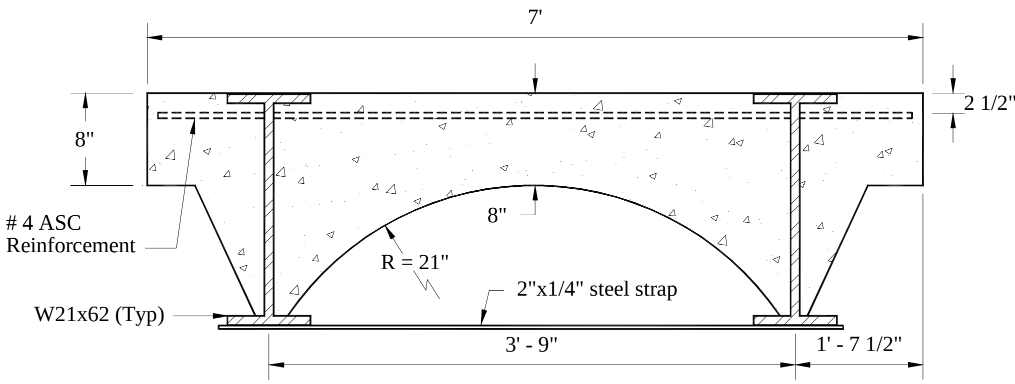
## SUMMARY AND CONCLUSIONS

Based on the limited number of specimens tested in this investigation, the following observations and conclusions can be made:

- The strength of the ASC was determined to be primarily a function of shear hole area, amount of transverse reinforcement, number of shear holes, and the concrete compressive strength.
- The ASC was determined to have adequate fatigue strength for use on low volume roads.
- Composite beam specimens with ASC reached their ultimate capacity without any distress in the ASC.
- Modifications, which will not effect the ease of construction of the bridge, can be made to the existing BISB to make it possible to use the system in situations requiring longer span lengths.




**a. Cross-section of specimen 4**




**b. Cross-section of specimen 5**

**FIGURE 8 Details of composite speciments (1 in=25.4 mm; 1 ft=305mm)**

## ACKNOWLEDGMENTS

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